Mixings, Lifetimes and Masses of B Hadrons at the Tevatron

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On behalf of the CDF and DØ collaborations
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Strengths of the Detectors

Largest samples of $B_s$, $B_c$, $B$-baryons at the Tevatron

$>5\text{fb}^{-1}$ recorded to date. Analyses today from 1.0 - 2.8 $\text{fb}^{-1}$

Excellent tracking and mass resolution.

Ability to trigger on displaced tracks ➔ Large sample of hadronic decays

Excellent Muon Id and tracking coverage ➔ Large samples of semileptonic decays

Regular magnet inversion ➔ smaller systematics in charge sensitive measurements
$\textbf{B}_s$ Mixing

- Flavor eigenstates $\neq$ mass eigenstates
- $\Delta m_s$, the mixing frequency $\Delta \Gamma$, the width difference

$\Delta m_s = 17.77 \pm 0.10 \text{(stat)} \pm 0.07 \text{ (syst)} \text{ ps}^{-1}$

5.4$\sigma$ statistical significance

$\Delta m_s = 18.53 \pm 0.93 \text{(stat)} \pm 0.30 \text{(syst)} \text{ ps}^{-1}$

2.9$\sigma$ statistical significance

PRL 97 242003

www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B54
Mixing frequency established ➔ use $B_s \rightarrow J/\Psi \phi$ to look for new physics

- $B_s$ mass eigenstate ~pure CP eigenstates in SM ($\phi_s \sim 0$)
- $B_s \rightarrow J/\psi \phi$ : CP of final state given by angular momentum $L$
- $L=0, 2$ ➔ CP even, $L=1$ ➔ CP odd

$B_s^0 \rightarrow J/\Psi \phi$ 

\[ \Rightarrow \sin(2\beta_s) \]

- Interference of both decay paths involves CP violating phase $\beta_s$
- $\beta_s \sim 0.02$ in standard model ➔ Large observed $\beta_s$ = New physics
- Analyse decay rate as a function of time, decay angles and initial $B_s$ flavor
- Extract lifetime, $\Delta \Gamma$, $\beta_s$ from unbinned likelihood fit
$B_S \rightarrow J/\Psi \phi$

Yield = $3166 \pm 56$

Yield = $1967 \pm 65$
Strong phases constrained by \( B^0 \rightarrow J/\psi K^* \) measurement → one minimum

Probability of consistency with SM = 6.6%

Confidence intervals for \( \beta_s \Delta \Gamma \) as errors non Gaussian

Probability of consistency with SM = 7.0% \( \sim 1.8\sigma \)

PRL 100 161802 (1.4 fb\(^{-1}\) result)

www-cdf.fnal.gov/physics/new/bottom/080724.blessed-tagged_BsJPsiPhi_update_prelim/
Similar deviations observed at CDF and DØ

Combination only for 1.35fb\(^{-1}\) (CDF)[1.5\(\sigma\) inconsistency observed] + 2.8fb\(^{-1}\) DØ

2.2\(\sigma\) deviation from SM

One to watch

Can expect:

More data - at least 8fb\(^{-1}\) of data by end of Run II

- use of data collected by other triggers

Improvement/Addition of tagging information
\( a_{sl}^s \) in semileptonic \( B_s \) Decays

Can provide additional constraints to \( \phi_s \)

Measurement of charge asymmetry using time-dependent analysis of:

\[
B_s \rightarrow D_s^- \mu^+ \nu X \left( D_s^- \rightarrow \phi \pi^-, \phi \rightarrow K^+ K^- \right)
\]

\[
a_{sl}^s = \frac{\Delta \Gamma}{\Delta m_s} \tan(\phi_s)
\]

Fix \( \Delta m_s = 17.77 \text{ps}^{-1} \)

\( a_{sl}^s \) in SM expected small \((\sim 2.06 \pm 0.57) \times 10^{-5}\)

\( a_{sl}^s = -0.0024 \pm 0.0117^{+0.0015}_{-0.0024} \)

Most precise measurement to date

www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B55
**B_s Lifetime**

Better measurement of $\tau(B_s)$ can also be used to constrain NP in $B_s$ mixing.

- Take advantage of yield of partially reconstructed $B_s$ decays
- 1100 fully reconstructed $B_s \rightarrow D_s \pi$
- 2200 partial reconstructed $B_s \rightarrow D_s^* \pi$, $B_s \rightarrow D_s \rho$

Consistent with $\tau(B_s) \sim \tau(B_d)$

$$ct = \frac{ML_{xy}}{P_T}$$

$ct = 455.0 \pm 12.2 \pm 8.2 \, \mu m$

www-cdf.fnal.gov/physics/new/bottom/080207.blessed-bs-lifetime/
Lifetimes of B Hadrons

Spectator model: all B hadrons have the same lifetime

Difference from light quark interactions

Expected Hierarchy:

\[ \tau(B_u) > \tau(B_d) \sim \tau(B_s) > \tau(\Lambda_b) >> \tau(B_c) \]

Ratio Predictions (HQE):

\[ \tau(B^+) = 1.06\pm0.02 \ \tau(B_d) \]
\[ \tau(B_s) = 1.00\pm0.01 \ \tau(B_d) \]
\[ \tau(\Lambda_b) = 0.88\pm0.05 \ \tau(B_d) \]


\[ \tau(B_c) = 0.55\pm0.15 \ \text{ps} \]

Previously, in \( B_s, \Lambda_b \) have seen 1-2\( \sigma \) discrepancies

PDG \( \tau(B_d) \): 1.530 \( \pm 0.009 \) ps
Lifetime measurements and the CDF track trigger

- Large Branching ratios to hadronic final states
- Use a Two Track Trigger with primary requirements:
  - Two tracks with $120 \mu m < \text{impact parameter} < 1000 \mu m$
  - $L_{xy} > 200 \mu m$
- Effectively triggers on displaced vertices $\Rightarrow$ high B Hadron yields
- Lifetime distribution biased

Two solutions
1. Use MC to determine average efficiency [$B_s$ and $\Lambda_b$]
2. Use simulation free method [$B^+$]
\( \Lambda_b \rightarrow \Lambda_c \pi \)

Large Signal yield

Sample composition determined from mass fit

Signal: $2927 \pm 58$
\( \tau(\Lambda_b) \) using MC to model the trigger efficiency

Fit exponential convoluted with trigger efficiency and detector resolution.

\[
c_\tau = 422.8 \pm 13.3 \pm 8.8 \, \mu \text{m}
\]

Systematic error dominated by MC modeling of trigger efficiency and decay

www-cdf.fnal.gov/physics/new/bottom/080703.blessed-lbcpi-ct/
**Λ_b Lifetime Comparisons**

- New measurement consistent with all previous measurements
- Agreement with theory prediction: $\tau(\Lambda_b) = 0.88 \pm 0.05 \, \tau(B^0)$

$$\tau(\Lambda_b) = 0.922 \pm 0.039 \, \tau(B^0)$$

- Utilise x4 increase in data for more precise measurements.
Simulation Free approach

• Using MC to determine trigger efficiency $\rightarrow$ dominates systematic error

• MC dependent method: systematic uncertainty $\sim$ 8-9 $\mu$m

• Developed new, simulation free approach to bias correction

• Takes only kinematic information from data: Calculates the probability the trigger accepts the event at any decay point

• Calculates “Event-by-Event” Efficiency function

Impact parameters too small  \hspace{1cm} Impact parameter in trigger range  \hspace{1cm} Impact parameters too large
\(\tau(B^+)\) using Simulation Free approach

- Tested on \(B^- \rightarrow D^0\pi\) (Yield \(\sim 24,000\))
- Result consistent with PDG \(491\pm3\ \mu m\)

- Systematic uncertainty \(4.5\ \mu m\ c.f.\ \sim 9\ \mu m\) for MC dependent approach

- New method + more data \(\Rightarrow\) high precision results for \(\Lambda_b\) and \(B_s\)

\[c\tau=498.2\pm6.8\pm4.5\ \mu m\]

www-cdf.fnal.gov/physics/new/bottom/080612.blessed-MCfree_Blifetime/
**B_c Lifetime**

- Semileptonic channels can also be used for lifetime measurement
- $B_c \rightarrow J/\Psi \ell X$
- Analyse both $e$ and $\mu$ channels
- Account for missing momentum with $K$ factor derived from MC

$$ct^* = \frac{ct}{K} = \frac{mL_{xy}(J/\Psi l)}{P_T(J/\Psi l)}$$

$ct^*$ = pseudo proper decay length

CDF: $ct = 142.5^{+15.8}_{-14.8} \pm 5.5 \, \mu m$
$B_c \rightarrow J/\Psi \mu X$ lifetime

\[ c\tau = 134.3^{+11.4}_{-10.8} \pm 9.6 \text{ } \mu m \]

Simultaneous fit to mass and lifetime - Most precise measurement to date

**Results from CDF & DØ consistent with each other and theory (165\pm45) \mu m**
$\Omega_b$ search

Tevatron has seen the observation of new b-baryons:
$\Sigma_b^\pm$ (2006), $\Xi_b^-$ (2007), $\Omega_b^-$ (2008)

• DØ search for $\Omega_b \rightarrow J/\Psi \Omega^-$
• Builds on the $\Xi_b^-$ discovery
• Data reprocessed allowing tracks with large impact parameter to be found.
  Increases yield of $\Omega$
• Boosted decision tree improves $\Omega^- \to \Lambda K$ signal

• Inputs are particle momenta, vertices, track qualities
\( \Omega_b^- \) Mass

- Observe \( 5.4\sigma \) significance
- \( N = 17.8 \pm 4.9 \pm 0.8 \)

- Theoretical predictions:
  - Mass \( \Omega_b^- = 5.94 - 6.12 \) GeV
  - Some predictions uncertainties ~ 50 MeV

\[ R = \frac{f\left( b \rightarrow \Omega_b^- \right) Br\left( \Omega_b^- \rightarrow J/\Psi \Omega^- \right)}{f\left( b \rightarrow \Xi_b^- \right) Br\left( \Xi_b^- \rightarrow J/\Psi \Xi^- \right)} \]

\( R = 0.80 \pm 0.32^{+0.14}_{-0.22} \)

Mass \( \Omega_b^- = 6.165 \pm 0.010 \pm 0.013 \) GeV

PRD 77 014031, PRD 77 034012

PRL 101 232002
Prospects

- This talk features analyses using 1.0-2.8 fb\(^{-1}\) of data
  - Already have many world’s best mass and lifetime measurements.
  - Only place capable of exploring CPV in B\(_s\) mixing
- Tevatron continues to deliver more data: \(\sim 5\) fb\(^{-1}\) recorded

Can expect:
- Improved mass determinations for new B baryons
- More precise lifetime measurements
- Signatures of new physics?
Backup
$\Phi_s$ and $\beta_s$ are not the same

$\beta_s = \arg\left[ -V_{tb}V_{ts}^* / V_{cb}V_{cs}^* \right] \sim 2.2^\circ \text{ (SM)}$

phase of $b \rightarrow ccs$ transition that accounts for decay and mixing+decay.

$\Phi_s = \arg[-M_{12}/\Gamma_{12}] \sim 0.24^\circ \text{ (SM)}$

$\arg[M_{12}] = \arg(V_{tb}V_{ts}^*)^2$ matrix element that connects matter to antimatter through oscillation.

$\arg[\Gamma_{12}] = \arg[(V_{cb}V_{cs}^*)^2 + V_{cb}V_{cs}^*V_{ub}V_{us}^* + (V_{ub}V_{us}^*)^2]$ width of matter and antimatter into common final states.

Both SM values are experimentally unaccessible by current experiments (assumed zero). If NP occurs in mixing:

$\Phi_s = \Phi_s^{SM} + \Phi_s^{NP}$

$2\beta_s = 2\beta_s^{SM} - \Phi_s^{NP}$

$\Rightarrow$ standard approximation: $\Phi_s = -2\beta_s$
PDG 07: $\tau(B_s) = 0.939 \pm 0.021 \, \tau(B_d)$

$\tau(B_s)$ measurements from $B_s \rightarrow J/\Psi \phi$ also higher than PDG 07

DØ : $\tau=1.52 \pm 0.05 \pm 0.01$ ps

CDF: $\tau=1.53 \pm 0.04 \pm 0.01$ ps

These recent measurements consistent with $\tau(B_s) \sim \tau(B_d)$